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TECHNICAL REPORT
EP-36

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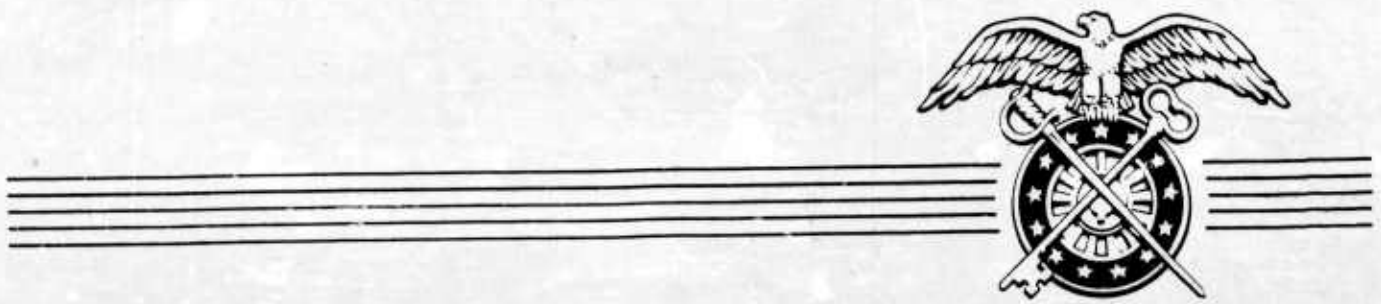

QUARTERMASTER RESEARCH & DEVELOPMENT CENTER
ENVIRONMENTAL PROTECTION RESEARCH DIVISION

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NATICK, MASSACHUSETTS

HEADQUARTERS QUARTERMASTER RESEARCH & DEVELOPMENT COMMAND
Quartermaster Research & Development Center, U S Army
Natick, Massachusetts

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VISIBILITY IN SOME FOREST STANDS OF THE UNITED STATES

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FOREWORD

Visibility is a matter of great importance to military operations, for maintaining contacts in the field, decid what type of weapons and sights to employ in specified environmen s, guarding against attack, and during actual combat. At the request of the General Staff, U. S. Army, the Quartermaster Research and Development Command undertook to study the effects of vegetation on visibility. The field work for the present study was carried out by Dr. Robert R. Drummond, American Geographical Society. Portions of the field results are presented here by Dr. Earl E. Lackey of the Environmental Analysis Branch, Environmental Protection Research Division of this Command. The results represent a pioneer study in the virtually untouched subject of quantitative effects of vegetation on visibility.

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ABSTRACT

Army personnel deployed in forested areas usually find it critically important to know how far through the vegetation cover associated men may be able to see each other, or the distance away that an enemy may be seen. This study is devoted to the exploration of this visibility problem. The following statements summarize the major findings:

1. On the whole there was no marked difference between visibility in summer in deciduous and coniferous stands. Where vegetation was mixed coniferous and deciduous, the conifers tended to be the dominant factor in limiting visibility.

2. In deciduous growths, visibility was about 40 percent greater in winter than in summer. In coniferous vegetation, visibility did not vary appreciably from season to season.

3. Visibility was greater in interrupted stands of deciduous vegetation than in stands where the branches of one tree touched the branches of the next tree. In tall coniferous vegetation also, visibility was greater in interrupted stands. In coniferous vegetation of medium and low heignt, visibility was greater in continuous stands than in interrupted stands.

4. Visibility tended to increase with the height of the primary vegetation cover (as opposed to undergrowth).

5. Visibility tended to decrease as the height of the undergrowth increased. Visibility was greatest when the height of the undergrowth was less than three feet; it was least when the height of the undergrowth was more than six feet.

6. Vines in undergrowth greatly reduced visibility. On an average, the reduction was about 36 percent.

7. Visibility in deciduous and coniferous forests rarely exceeded 100 yards. One-third of all stands of representative vegetation in the United States that were investigated had visibilities between 30 and 50 yards. Nearly half had visibilities between 30 and 60 yards.

VISIBILITY IN SOME FOREST STANDS OF THE UNITED STATES

1. Introduction

Continuous visibility is dependent on many factors, including (1) terrain; (2) condition of the atmosphere; (3) vegetation cover; (4) contrasting backgrounds; (5) intensity of light; (6) quality of human sight; (7) size and activity of the object under surveillance; and (8) training and judgment of the observer. For purposes of this study all these factors are assumed constant and optimum for continuous visibility, except the variable under investigation, the vegetation cover. The garment of vegetation may vary from large deciduous and evergreen trees to low grasses, forbs, lichens and mosses; from plants less than 3 feet in height to those 75 feet or more high; and from a continuous canopy of foliage and branches to widely disconnected patches and clumps of plants.

Despite the importance of vegetation in limiting visibility, the subject does not appear to have been treated systematically heretofore. Only scattered published references appear, such as the statement that the dense primary jungle in Central Burma limits the range of vision to 20 yards (Gilinski, 1951, p. 247).

a. Definition of "Continuous Visibility"

For the purpose of this report the term "continuous visibility" is defined as the greatest distance to which a quiet, erect, stationary man can be kept in constant view as the observer goes away from him.

b. Scope of the Investigation

Continuous visibility within various stands of vegetation is limited by numerous factors, important among which are: (1) persistence and seasonal change of foliage (evergreen, deciduous, mixed); (2) height (primary growth, undergrowth); (3) density and continuity (trunks, branches and foliage); and (4) vines.

The major purpose of this investigation was to find within the United States representative combinations of the above vegetation factors, to measure continuous visibility in each sample area, and to record results by the use of tables, graphs and maps.

2. Method of Investigation

The study of limits of continuous visibility in this investigation required: (1) a relatively simple classification of the innumerable combinations of vegetation, and (2) a workable procedure for measuring

the distance that the standard visibility object could be seen through the vegetation.

a. Classification of Vegetation

The almost innumerable variations in vegetation types made mandatory a classification with significance for a study of visibility. Such a classification of vegetation must accommodate a wide variety of species and sizes as well as the combination of various levels and heights of vegetation in any specific area. The classification system should be useful not only in examining small areas, but also in making wide areal generalizations. Furthermore, the system should aid in minimizing subjectivity in field investigations.

The classification system which satisfies these requirements is Kuchler's physiognomic classification of vegetation (Kuchler, 1949; Goode, 1950). This system was used with only slight modifications (see key to Table I). By use of its simple set of letter symbols, an area's vegetation can readily be classified not only into generic groupings but also into significant categories of height and density of growth.

The practicality of this system was demonstrated in the field; four staff members, working separately in vegetation stands with highly similar features, almost invariably produced identical classifications.

In field investigations, a given stand of vegetation was classified according to the nature of both its primary growth and its undergrowth. For example, a primary growth of deciduous broadleaf forest (D), in which the trees are 75 or more feet tall (t), and the canopy interrupted (i)-the branches of the indivdual trees do not touch - is classified as Dti. Its undergrowth of grass (G) with a continuous (c) cover less than 3 feet in height (z) is classified as Gzc. The entire stand (primary growth plus undergrowth) is classified Dti/Gzc. If vines were present in a given stand of vegetation, they are noted with a "j", e. g., Dmc/Dsi(j). In field investigation it was soon observed that primary growth and undergrowth groupings tended to fall into regular and readily observed combinations. This served to simplify somewhat the tabulation of field data.

b. Standard Visibility Object

The visibility object used as a standard throughout the investigation was a green cylinder six feet in height and one and one-half feet in diameter (Fig. 1). The cylinder was constructed from a framework of metal pipe and plywood, and fitted with a cover of canvas cloth

Figure 1. Standard visibility object (SVO) set up in the field

dyed a medium-dark green.* This size was chosen to simulate the dimensions of a man plus his military equipment. Various sizes of stakes and signs were tried but none proved as effective as the cylinder in its similarity to the human form. It was assumed that the standard visibility object (SVO) represented a man - erect and motionless.

c. Determination of Visibility

In any specific area, a representative stand of vegetation was sought and classified according to Küchler's classification (Küchler, 1949). The standard visibility object (SVO) (Fig. 1) was set up in the midst of the stand (Figs. 2 to 7). The observer then paced away from the SVO until it could no longer (or just barely) be seen. This paced distance was then recorded, to be converted later into yards. The visibility distance was paced in four or more directions and then averaged. The observer in general kept to a straight-line path, although minor deviation was allowed (e.g., where a large tree trunk might block visibility) in order to keep the SVO in continuous view.

Attempts were made to eliminate extraneous physical factors from the visibility readings, and to control the human factor as far as possible. Areas were chosen in which terrain played no part in limiting visibility. Readings were made when the sun was high above the horizon, in order to minimize the effect of shadows.** When readings were made in mid-morning, visibility distances were paced in as many as eight different directions in order to obtain a reliable measurement. In nearly all cases the distances obtained in the several directions away from the visibility object in any one stand were highly similar. As a rule the separate readings in a single stand of vegetation varied no more than 2 to 4 percent. All observers possessed natural or corrected 20/20 vision. Each observer's pace was separately equated in yards.

d. Recording the Field Data

The following information concerning the 392 stands of vegetation was recorded on 3" x 5" cards: (1) symbols indicating type, height and density for both primary growth and undergrowth; (2) season and month of the year; (3) state and location of the stand; (4) names of trees in the primary growth; (5) notes concerning the nature and kinds of undergrowth; and (6) the average visibility distance in each stand as paced in several directions from the SVO.***

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* Color corresponded closely to O.D., Q.M. Shade No. 8.

** The density of the overhead canopy of branches and foliage in a forest affects continuous visibility: (1) by modifying the amount of light that reaches the level of investigation (lowest 6 feet), and (2) by producing dappled effects (camouflage), thus making discernment the more uncertain.

*** See sample data cards in Appendix.

Figure 2. Standard visibility object being carried through interrupted stand of southern conifers, located 5 miles northwest of Alexander City, Alabama (Classification Emi/Ezi). Visibility distance, 55 yards.

Figure 3. Dense growth of conifers near Round Lake, Michigan. A stand of vegetation in the Emc/Dzc category. Visibility distance, 65 yards. SVO not shown in this picture.

Figure 4. Dense stand of deciduous (birch) trees near Luxemburg, Wisconsin (Classification Dmc/Dsc).

Figure 5. Standard visibility object nearly obscured at close range in a dense deciduous undergrowth (Classification of undergrowth, Dlc(j); "j" indicates vines).

Figure 6. Second growth area of mixed conifers, with dense bracken undergrowth (Classification Elc/Dzc). Visibility distance, 13 yards. Mt. Rainier National Park.

Figure 7. Dense growth of mixed deciduous and conifers, with vines, three miles south of Birmingham, Alabama (Classification Mmc/Dsc(j)). Visibility distance, 22 yards.

3. Extent of the Investigation

Field investigations were carried on in representative stands of the following types of vegetation in the United States (Küchler's classification): evergreen needleleaf; deciduous broadleaf; mixed deciduous broadleaf and evergreen needleleaf; grasses or prairie; evergreen broadleaf dwarf shrubform; desert; and tundra (Alpine).

A total of 392 stands of vegetation were examined (see Fig. 8). These include 147 stands of deciduous broadleaf growth; 119 stands of evergreen needleleaf (coniferous) vegetation; 111 stands of mixed evergreen needleleaf (coniferous) and deciduous broadleaf; 4 stands of pure grass; 7 stands of evergreen broadleaf; and 4 areas of Alpine tundra where lichens were the only growth.

Field work was carried on from September through November 1952, and August 1953 through January 1954, in the states shown in Figure 8.

4. Analyzing and Evaluating the Data

a. Organizing and Tabulating the Results of Field Studies

Table I is composed of four columns (A, B, C and D) and nine horizontal sections (1 to 9). The columns are differentiated chiefly on the basis of the foliage of the primary growth (deciduous, evergreen, etc.). The sections deal with height and density first of the primary growths, and secondly of the undergrowth (Kittredge, 1948).

The 36 compartments are designed to cover the natural vegetation of the United States. The number would have to be increased if tropical and subtropical areas outside the United States were to be included. In the deciduous columns, less than half of the compartments are occupied, which indicates an incomplete coverage, whereas every compartment in the evergreen needleleaf column is occupied.

In each occupied compartment is indicated the over-all average visibility distance for comparison either among primary growths with the same kind of foliage (columns), or of primary growths of the same height but with different types of foliage (sections). For example, in Column A, the average visibility distances approximately are: Dtc, (deciduous, tall, closed canopy), 26 yards; Dmc, (deciduous, medium, closed canopy), 62 yards; Dmi, (deciduous, medium, interrupted canopy), 82 yards; Dlc, (deciduous, low, closed canopy), 32 yards; and Dlp, (deciduous, low, patchy canopy), 69 yards. In Section 1, dealing with tall-tree growth, the average visibility distances are: Dtc, (deciduous, tall, closed canopy) 26 yards; Etc, (evergreen, tall, closed canopy), 71 yards; and Mtc, (mixed, tall, closed canopy), 52 yards.

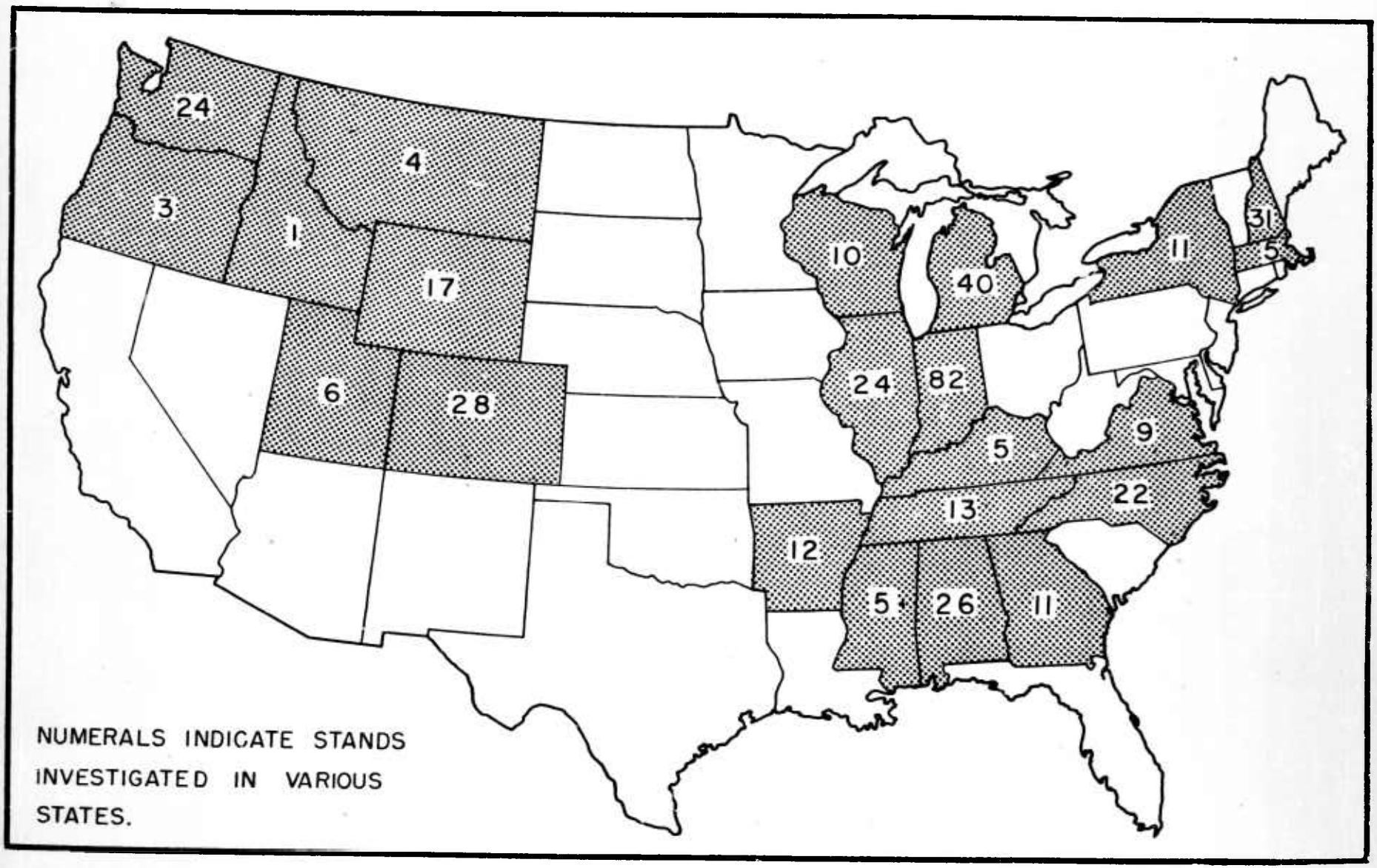

Figure 8. States (22) where investigations were made (total 392 stands)

SECTIONS	A. Summer Deciduous						B. Winter Deciduous						C. Evergreen Needleleaf						D. Mixed (and others)						SECTIONS
	Primary Growth	Undergrowth	Number Readings	Av. Visibility (yds)	Av. Deviation (yds)	Vine Deviation (per cent)	Primary Growth	Undergrowth	Number Readings	Av. Visibility (yds)	Av. Deviation (yds)	Vine Deviation (per cent)	Primary Growth	Undergrowth	Number Readings	Av. Visibility (yds)	Av. Deviation (yds)	Vine Deviation (per cent)	Primary Growth	Undergrowth	Number Readings	Av. Visibility (yds)	Av. Deviation (yds)	Vine Deviation (per cent)	
1	Dtc Av. 26	Dlo Dsc Dsi	3 5 2	18 29 30	1 12 3								Etc Av. 71	Dlc Dli Dsc Dsi Eli Esi Msc Gsi	4 5 [illegible] 2 3 1 1 1	63 63 79 101 47 84 37 92	5 17 4 1 0 0 0		Mtc Av. 52	Dsi Msc Msi	1 2 5	67 48 40	0 3 3	12	1
2													Eti Av. 83	Dsi Esi Esi Gsc Gsi	7 1 1 1 1	57 40 76 110 132	7 0 0 0 0		Mti Av. 57	Dsc	1	57	0		2
3	Dmc Av. 62	Dlc Dli Dsc Dsi Dsc Dsi Mmo	4 6 5 11 3 11 1	29 57 41 61 40 92 112	3 18 18 13 15 7 0	19 58 38 37 46	Dmc Av. 83	Dlc Dli Dsc Dsi Dsi Gsc	9 17 4 15 7 1	74 86 88 76 95 78	8 21 9 13 16 0	44 10	Emc Av. 55	Dli Dsi Dsc Dsi Esi Esi Esi Gsi Mmc	3 2 1 6 3 2 2 15 2	51 44 65 48 40 98 48 50 52	3 8 0 8 4 1 5 9 9	32	Mmc Av. 45	Dlc Dli Dsc Dsc Dsi Eli Esc Esi Mlc Msc Msi Msi Esi Gsc	5 2 11 1 4 2 1 2 1 22 24 5 1 6	32 37 38 52 47 35 39 46 33 37 42 37 66 91	7 1 7 0 5 0 0 10 0 8 8 12 0 19	5 50 37 3 33 48 42	3
4	Dmi Av. 82	Dli Dsc Dsi Gsc	1 5 3 3	90 20 85 132	0 4 29 9		Dmi Av. 84	Dlc Dli Dsc Dsi Gsi	1 3 1 1 1	40 116 129 80 56	0 2 0 0 0		Emi Av. 41	Dsc Dsi Esi Esi Mlc Msc Msc Lsc Osc	1 2 4 5 1 1 4 2 2	44 22 41 42 25 29 50 55 57	0 1 13 5 0 0 22 18 17		Mmi Av. 33	Dlc Mli	4 1	31 34	11 0	52	4
5	Dlc Av. 32	Dsc Dsi Hsc Gsc Mmo	1 1 4 2 3	48 45 46 44 7	0 0 3 4 0		Dlc Av. 58	Dsc Dsi Dsi	3 4 4	70 56 48	9 14 20	58	Elc Av. 35	Dsi Dsc Dsi Hsc Osc Gsi Mmo	1 3 1 2 3 1 2	43 44 40 27 16 51 43	0 1 0 13 3 0 1	65	Mlc Av. 38	Dsc Dsc Msc Msc Msi Msc None	2 1 2 1 5 4 3	41 47 16 28 37 48 46	11 0 0 0 7 8 1		5
6													Eli Av. 39	Dlc Dsc Gsi Mmo	2 4 2 1	26 24 55 49	1 3 6 0		Mli Av. 29	Dsc Hsc	1 1	18 40	0 0		6
7	Dlp Av. 69	Dsc Gsc	1 1	72 65	0 0								Elp Av. 166	Osc	1	166	0		Glc Av. 32	None	4	32	3		7
8													Esi Av. 54	Dsi Gsi	3 1	58 50	9 0		Bsi	None	7	oo	0		8
9	Total Average		76	47[2]	9.8[2]	40[1]			71	75[2]	14.4[2]	37[1]	Esi	Lsi	4 119[3]	oo 49[2]	0 9.9[2,4]	48[1]	Lsi	None	4 126[3]	oo 43[2,4]	0 8.6[2,4]	31[1]	9

Total No. Readings[3].....392
Mean Av. Visibility[2].....51.8 yds.
Mean Av. Deviation[2].....10.4 yds.
Mean Vine Deviation.....36.3%

TABLE I: Averages of Vegetation Visibility Readings

Key to Classification (Modified from Küchler)

Vegetation

- B Evergreen broadleaf
- D Deciduous broadleaf
- E Evergreen needleleaf
- G Grass
- H Forbs
- L Lichens and mosses
- M Mixed deciduous and evergreen needleleaf

Height

- t Tall; minimum height, 75'
- m Medium; 30' - 75'
- l Low; 6' - 30' (high for undergrowth)
- s Shrub-like; 3' - 6' (medium for undergrowth)
- e Dwarf-shrub-like; under 3' (low for undergrowth)

Density

- c Continuous growth; upper branches touching
- i Interrupted growth; trees do not touch
- p Growth in disconnected patches

j Vines (incorporated in separate column above)

Source for classification key:
A. W. Küchler, "A Physiognomic Classification of Vegetation," Annals of the Association of American Geographers, Vol. XXXII, No. 3, Sept., 1949, 201-210.

Notes:

[1] Vine deviation means the per cent by which the average visibility of "vine readings" in any one category is lower than the average of "non-vine readings" in that category. No entry in any category indicates the absence of readings with which to compare.

[2] In computing this average, only categories which contained four or more readings were used.

[3] This total includes the readings in the Esi category for Coniferous Needleleaf, and in the Olc, Lsi, and Bsi categories for Mixed Vegetation.

[4] This figure does not include the average visibilities in the Esi category for Coniferous Needleleaf, and in the Olc, Lsi, and Bsi categories for Mixed Vegetation.

In each section of Table I, the symbols for primary growth are shown in combination with several kinds of undergrowth. For example, the first line of Section I is a record of Dtc (deciduous, tall, closed canopy) primary growth associated with Dlc (deciduous, high, closed canopy) undergrowth. The two taken together (Dtc/Dlc) constitute a category in which three observations were made, averaging about 20 yards.

The average visibility distances for all categories in which four or more stands were measured are grouped as follows (Section 9): deciduous summer, 50 yards; deciduous winter, 75 yards; evergreen needleleaf, 50 yards; and mixed, 40 yards.

In deciduous forests one may keep visual contact with friendly forces or see enemy forces 50% to 60% farther in winter than in summer. In summer, average visibilities among primary growths with different types of foliage do not differ by more than a few yards.

In categories in which vine-clad and vine-free stands could be compared, the vines reduced the visibility distance by amounts varying from 3% to 65%.

b. Usable Categories for Statistical Analysis

The readings from 392 stands fell into 113 different categories, or combinations of primary growth and undergrowth, according to Küchler's classification. In most categories too few stands were measured to make possible statistically significant conclusions. Of the 113, 24 were represented by 5 or more stands (Column 2, Fig. 9). One of these stands (Bzi, line 59, Fig. 9) presented unlimited visibility. The remaining 23 categories of forest vegetation, comprised of 203 stands, were used in computing the standard deviations shown in Column 6, Fig. 9.

Figure 9 presents to scale several measures of each of the 23 categories. For example, in the Dmc/Dli category (line 21), the average visibility distance for 17 stands was about 85 yards, the standard deviation 25 yards, the minimum and maximum distances 47 and 127 yards, and the standard error of the mean, ± 4 yards. (See the yardage bar for line 21, drawn to scale.) If it is assumed that the 17 stands approximate a normal distribution, it may be expected that two-thirds of Dmc/Dli stands should have average visibility distances within 25 yards of the mean (86 yards) i.e., between 60 and 110 yards. The average visibility distance of two-thirds of any other 17-stand sample composing the true average should be within 4 yards of the average of the present 17-stand sample (86 yards), that is between 82 yards and 90 yards.

Soldiers deployed in deciduous forest of closed-canopy trees with a low interrupted deciduous undergrowth (Dmc/Dli) could be guided in

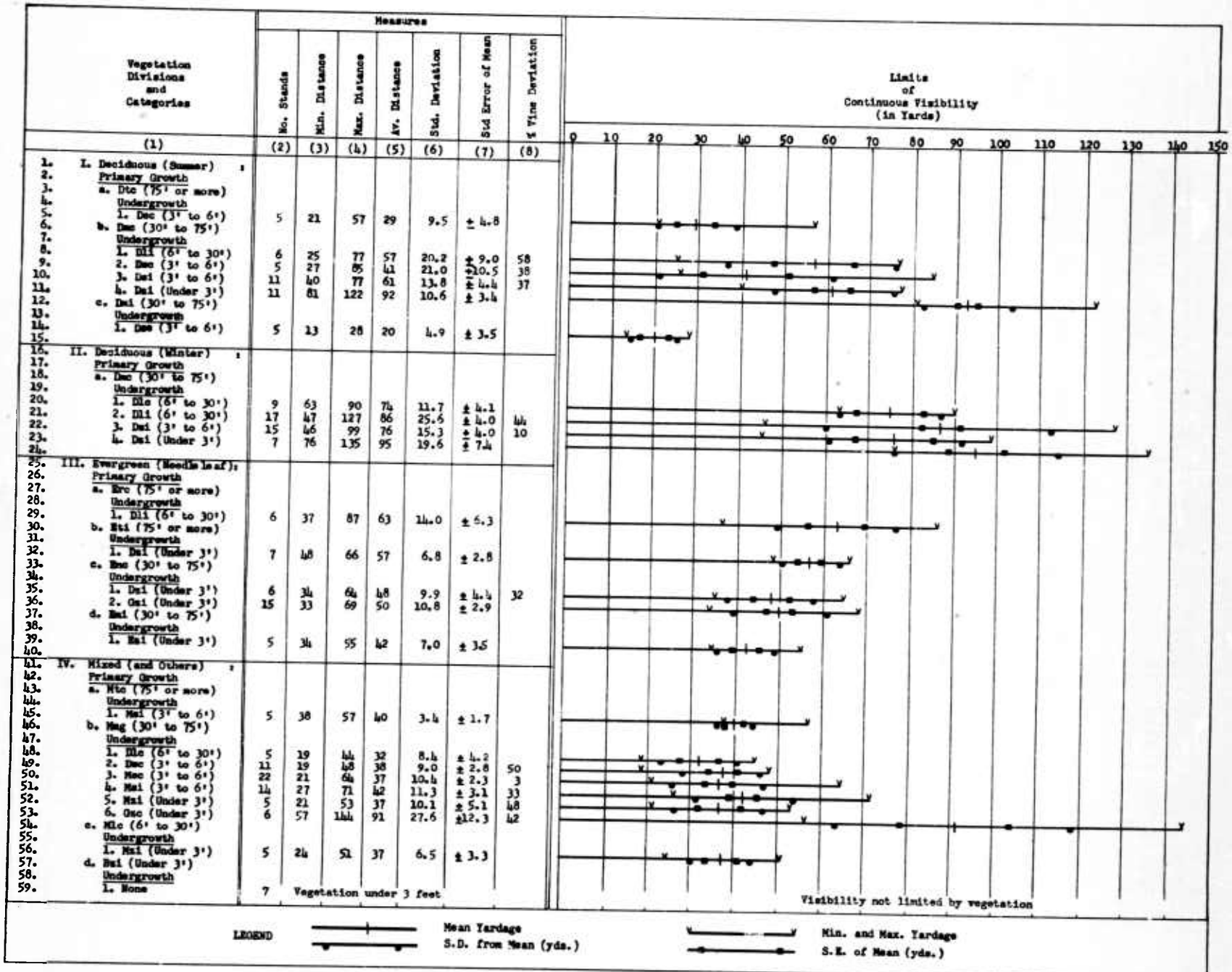

Figure 9. Continuous visibility as related to various vegetation covers

keeping visual contact with members of their own party (or in seeing an enemy) by the visibility distances drawn to scale above. It should be remembered, however, that visibility distances are also contingent on the assumptions stated in paragraph 1.

c. Assessing Some Probable Limits to Continuous Visibility in Forests

Only eight categories in Table I contain observations in as many as eleven stands of forest. These observations provide a rough estimate of the probable distance one should be able to see a man in these types of vegetation. The probable visibility distances for these categories may be read from Figure 10, and the average or 50-percentile distances are shown in diagrammatic form in Figure 11. Some representative distances are listed in Table II. The standard error of the mean in the first category of this table is ± 4.4 yards, which indicates the chances are 68% that the mean of the present 11-stand category (61 yards) is within 4.4 yards of the true mean of all stands of this category.

Likewise, the probability yardage at the various percentile points 68% of the time, should not differ from the true yardage by more than the indicated yardage error. (See Kendall, 1948, and notes associated with Table II.)

5. Findings

a. Difference in Visibility Between Coniferous and Deciduous Forest

On the average, continuous visibility through coniferous and deciduous vegetation in summer shows little difference. The average visibility through all deciduous (summer) vegetation is 47 yards; through all coniferous, 49 yards. A comparison of the different categories within these two main groups, however, reveals certain important differences. In tall stands (i.e. more than 75 feet high) of continuous vegetation, coniferous forest is much more open than deciduous forest, and visibility distances are three times as great. The presence of vines is a factor in the cutting down of visibility through deciduous growths. Vines as a rule do not occur in coniferous stands. In stands of medium height and continuous canopy, there is no appreciable visibility difference between deciduous and coniferous; but in stands of medium height with interrupted canopy, visibility in coniferous growth is only 50% that in deciduous growth. In low stands the visibility in coniferous growths again shows little difference from that of deciduous growth. Investigators noted that in nearly all stands where vegetation is mixed deciduous and coniferous, the conifers were the dominant factor in limiting visibility.

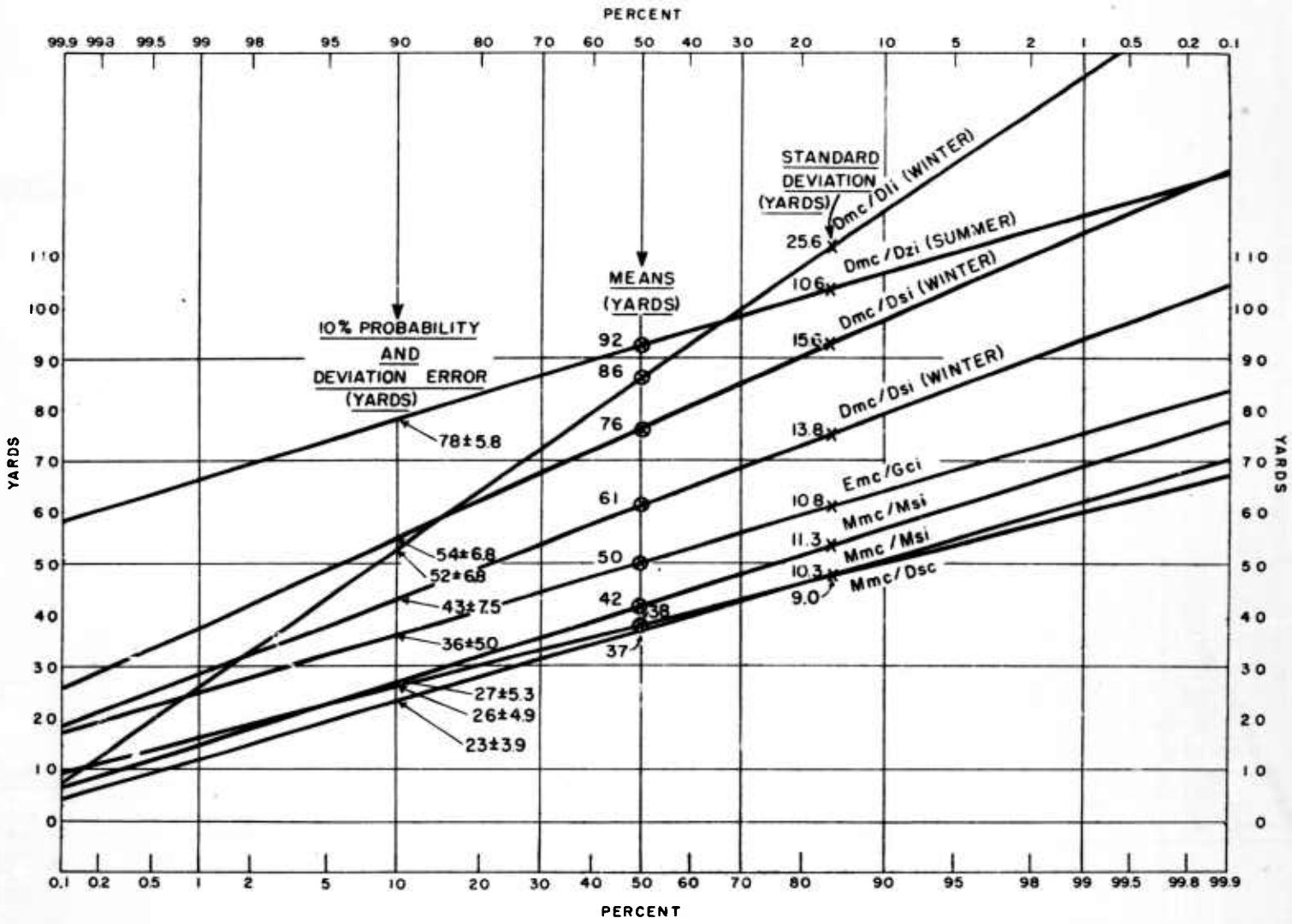

Figure 10. Probable visibility distances in eight vegetation categories (Data from Fig. 9. Summary in Table II)

A schematic diagram showing average limits of visibility in selected forest communities.

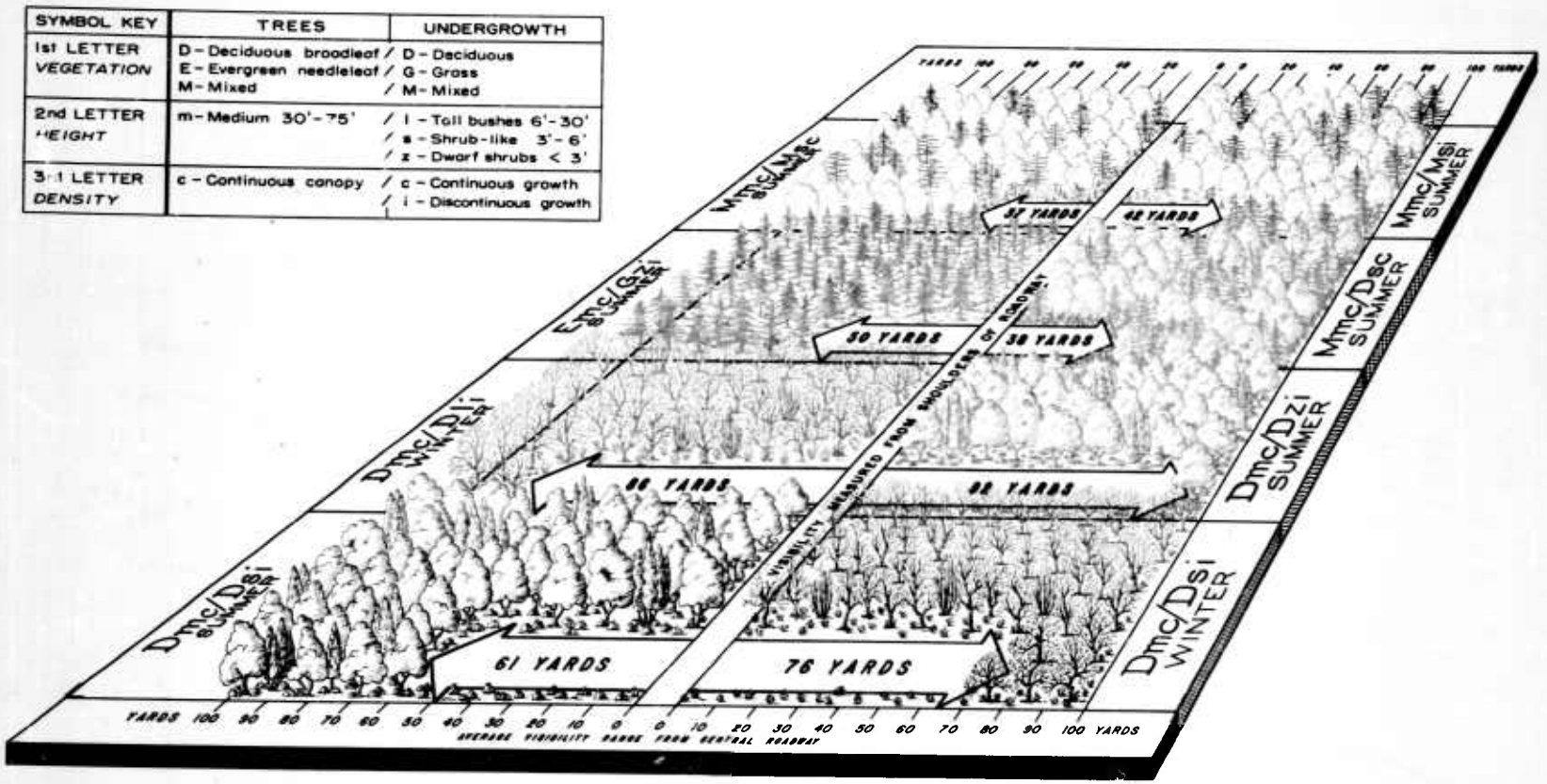

Figure 11. Continuous visibility as related to forest types

TABLE II: VISIBILITY PROBABILITIES IN RANDOM STANDS OF SELECTED CATEGORIES OF VEGETATION

Line On Fig.9	Vege-tation	No. Stands	Minimum Distance Observed	95%	90%	80%	50%	20%	10%	5%	Maximum Distance Observed
10*	Dmc/Dsi Summer	11	40	38	43 ± 7.5	49 ± 6.3	61 ± 4.4	73 ± 6.3	79 ± 7.5	84	77
11	Dmc/Dzi Summer	11	81	74	78 ± 5.8	83 ± 4.9	92 ± 3.4	101 ± 4.9	106 ± 5.8	110	122
21	Dmc/Dli Winter	17	47	44	52 ± 6.8	64 ± 5.7	86 ± 4.0	107 ± 5.7	119 ± 6.8	128	127
22	Dmc/Dsi Winter	15	46	48	54 ± 6.8	61 ± 5.7	76 ± 4.0	89 ± 5.7	96 ± 6.8	102	99
36	Emc/Gzi	15	33	32	36 ± 5.0	41 ± 4.1	50 ± 2.9	59 ± 4.1	64 ± 5.0	68	69
49	Mmc/Dsc	11	19	23	26 ± 4.9	30 ± 4.0	38 ± 2.8	45 ± 4.0	50 ± 4.9	53	48
50	Mmc/Msc	22	21	20	23 ± 3.9	28 ± 3.3	37 ± 2.3	46 ± 3.3	50 ± 3.9	54	64
51	Mmc/Msi	14	27	23	27 ± 5.3	32 ± 4.4	42 ± 3.1	51 ± 4.4	57 ± 5.3	61	71

*Sample reading in line 10: In a Dmc/Dsi stand, there is a 10% chance (1 chance in 10) that a man could be seen 79 or more yards away; 50% chance (average), 61 or more yards away; and 90% chance (9 chances in 10), 43 or more yards away. Moreover, at the 10-percentile point, there is a 68% chance (2 chances in 3) that the true probability will not differ from the probability of this 11-stand sample (79 yards) by more than 7.5 yards.

The other probabilities and reliabilities are to be read in a similar manner.

NOTE: When the maximum and minimum yardages are compared with the 5- and 95-percentile probable values, one is encouraged to believe that this method of assessing probable visibility distances in forested areas has considerable merit. Although in only two or three cases did the maximum and minimum distances at the 5- and 95-percentiles probabilities fall outside the deviation error, it is urged that caution should be exercised if chances at or beyond these extremes are undertaken.

b. Seasonal Variation in Visibility

A study was made of deciduous vegetation in summer and winter to ascertain to what extent seasonal variation in foliage limits visibility. Fall readings were classified with those for summer if trees still retained most of their leaves; if most of the leaves were gone the fall readings were grouped with those for winter. All fall readings were taken in northern and central Illinois and Indiana. It was found that visibility in deciduous stands averages 37% greater in winter than in summer. No seasonal difference was noted in evergreen stands. Seasonal variation was not investigated in mixed stands.

c. Density of Vegetation as a Factor in Visibility

Three density categories came within the scope of this investigation: continuous growth, interrupted growth, and growth in patches or clumps. In deciduous and coniferous vegetation the average visibility is generally highest where low primary growth occurs in clumps, and the undergrowth is less than 3 feet high.

Interrupted stands of medium-height deciduous trees permit about 30% more visibility in summer than did corresponding continuous stands. In winter there seems to be little difference between interrupted and continuous stands. In tall stands of conifers and of mixed deciduous and conifers, visibility in interrupted growth exceeds the visibility in continuous growths by an average of 14 percent.

In medium and low conifer stands, on the other hand, visibility in interrupted growth averages 16% less than the visibility in continuous growths. A possible explanation for this condition lies in the fact that continuous upper growth seems to restrict undergrowth; thus undergrowth is only a small factor in limiting visibility where the primary growth is continuous, but becomes a considerable factor where the primary growth is interrupted.

In both deciduous and coniferous stands, visibility is in inverse proportion to the density of the undergrowth, providing the undergrowth is so tall that it interferes with vision.

d. Height of Vegetation as a Factor in Visibility

Visibility seems to be directly related to the height of both primary growth and undergrowth. For primary growth, the conifers in particular show a well-defined visibility-height relationship. Among conifers and mixed conifers and deciduous, visibility is greatest in the tallest stands and least in lowest stands (Table III).

TABLE III: AVERAGE VISIBILITY IN PRIMARY STANDS OF VARIOUS HEIGHTS (IN YARDS)

Height of Primary Growth	Deciduous		Coniferous	Mixed
	Summer	Winter		
Over 75 ft. (tall)	26	(no data)	76	54
30 to 75 ft. (medium)	69	83	48	44
Under 30 ft. (low)	32	58	36	36

In deciduous forest, visibility is greatest in stands of medium height. Tall deciduous trees usually are accompanied by relatively dense undergrowth, often including vines, which reduce visibility. Likewise, where trees are low, undergrowth is a large factor in impeding visibility. Low trees are also more likely to have low branches interfering with visibility.

The relative height of the undergrowth is one of the most important factors in limiting visibility (Tables IV and V).

TABLE IV: AVERAGE VISIBILITY IN UNDERGROWTH OF VARIOUS HEIGHTS, AS RELATED TO TYPE OF PRIMARY GROWTH (IN YARDS)

Height of Undergrowth	Type of Primary Growth				
	Deciduous		Coniferous	Mixed	Average
	Summer	Winter			
Over 6 ft.	43	84	42	33	51
3 to 6 ft.	43	72	55	38	52
Under 3 ft.	75	76	50	53	64

The taller the undergrowth the less the visibility. In deciduous (summer) undergrowth, a modification of this principle is in order, because undergrowth over six feet tall tends to have most of its foliage above eye level, whereas the foliage in undergrowth three to six feet high occurs at eye level.

TABLE V: AVERAGE VISIBILITY IN UNDERGROWTH OF VARIOUS HEIGHTS AS RELATED TO HEIGHTS OF PRIMARY GROWTH (IN YARDS)

Height of Undergrowth	Height of Primary Growth (feet)		
	Over 75	30-75	Under 30
Over 6 ft.	52	60	26
3 to 6 ft.	50	60	47
Under 3 ft.	64	66	42

e. Vines as a Factor in Limiting Visibility

Vines were encountered in 61 of the 392 vegetation stands examined. In six of these stands, vines affected all measurements. Vines were present for the most part in deciduous and mixed stands; in only three coniferous stands were vines encountered. The investigators noted that wherever vines occurred, they were an important factor in reducing visibility. This observation is borne out in a comparison of the average for the "vine" readings with the average for "non-vine" readings in the separate categories. The vines reduce visibility by 36 percent, on the average. The presence of vines and the extent to which they limit visibility in some of the categories is apparent in Table I and Figure 9.

f. "Average" Visibility

The average for all the visibility readings with four or more stands is 52 yards. Only 11 times out of 377 forest stands was a visibility of over 100 yards recorded. There are only 4 recorded values less than 10 yards. The most frequently occurring values are between 30 and 50 yards; one third of all readings fall within this range. Nearly half of all readings fall between 30 and 60 yards. The distribution of visibility readings is shown in Table VI.

TABLE VI: DISTRIBUTION OF 392 VISIBILITY READINGS

Yards	Number of Readings	Percent Total Readings
0-10	4	1
11-20	20	5
21-30	46	12
31-40	70	18
41-50	63	16
51-60	47	12
61-70	31	8
71-80	32	8
81-90	23	6
91-100	19	5
101 and over	37	9
	392	100

6. Suggested Additional Studies

Since this investigation was designed largely as a pilot study, it was severely limited in scope by the criteria set up in the introduction. It seems important, therefore, to raise here some phases that call for additional or more intensive investigation.

a. Many stands of each category should be measured so that statistical techniques may be further applied.

b. The position of the observer should be fixed and SVO's moved outward in various directions to the limits of continuous visibility.

c. Some of the factors held constant in this study should be released; for example, continuous visibility usually would be decreased in rugged terrain.

d. Visibility in strategically important types of vegetation outside the United States should be measured; for example, rain forest, and jungle in Central America.

e. The direction of measurements from the SVO should be rigorously controlled to improve randomness.

f. Auxiliary observations should be made of stand density and growth habit. Such silvicultural factors as basal area, stem density, number of board feet or trees per acre and average diameter at breast height may also be measured.

g. Visibility distances in forests that have no obstructing

undergrowth or low-hanging branches should be explored. For example, what percentage of visibility is lost because of tree trunks alone at various distances from the SVO and from the observer? Geometric considerations indicate that measurements on trunk size and areal density, data obtainable from forestry sources, may be sufficient to determine visibility.

h. From vegetation keys to air photographs procedures should be developed for estimating visibility distances on the ground.

i. Relations between horizontal visibility near the ground, as discussed here, and the transmission of light from above through the forest canopy should be explored.

j. Slant visibility in the forest should be determined, that is, the distance an observer in an airplane can see through the cover as in an airdrop situation.

7. Acknowledgments

Substantial assistance in planning and executing the field work in this project was rendered by Dorothy Weitz Drummond, William Kowitz, and Robert Sinclair - members of the staff of the American Geographical Society. Credit is due to Michael Slauta of the Military Liaison Office, to Dr. W. F. Wood, William B. Anderson, Harry S. McPhilimy, and Carl W. Ross of the Environmental Analysis Section for helpful criticism, and to Andrew D. Hastings for the cartographic expression of visibility in Figure 11.

At the inception of this investigation Dr. Peveril Meigs lent direction and impetus to the study, and in its later stages the counsel and encouragement of Dr. David H. Miller and Col. Herbert Rasche were very helpful.

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APPENDIX A: SAMPLE DATA CARDS

17 Yards — Dtc / Dlc(j)

Time: Early September (7/3/53)

Place: Kentucky Dam State Park

Trees: elm, black gum, maple, willow, red ash, cypress

Notes: undergrowth - small trees (willow), brush, fallen trees, vines

(One of 3 stands in the category)

47 Yards — Emc / Gzi

Time: Mid September

Place: 8 miles west of Berthod Pass, Colorado

Trees: Engelmann spruce, lodgepole pine, small douglas fir

Notes: undergrowth - grass and small trees

(One of 15 stands in the category)

38 Yards — Mmc / Msi

Time: Mid September

Place: 19 miles south of Clarksville, Virginia

Trees: short-leaf pine, dogwood, oak, yellow poplar, maple

Notes: undergrowth - small trees, grasses, weeds

(One of 14 stands in the category)

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1. On the whole there was no marked difference between visibility in summer in deciduous and coniferous stands. Where vegetation was mixed coniferous and deciduous, the conifers tended to be the dominant factor in limiting visibility.
2. In deciduous growths, visibility was about 40 percent greater in winter than in summer. In coniferous vegetation, visibility did not vary appreciably from season to season.
3. Visibility was greater in interrupted stands of deciduous vegetation than in stands where the branches of one tree touched the branches of the next tree. In tall coniferous vegetation also, visibility was greater in interrupted stands. In coniferous vegetation of medium and low height, visibility was greater in continuous stands than in interrupted stands.
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7. Visibility in deciduous and coniferous forests rarely exceeded 100 yards. One-third of all stands of representative vegetation in the United States that were investigated had visibilities between 30 and 50 yards. Nearly half had visibilities between 30 and 60 yards.

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